REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

FORESTRY REMOTE SENSING LABORATORY,
SCHOOL OF FORESTRY AND CONSERVATION
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

A Coordination Task Carried Out in Cooperation with
The Forest Service, U.S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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THE USE OF SPACE AND HIGH-ALTITUDE AERIAL PHOTOGRAPHY TO CLASSIFY FOREST LAND AND TO DETECT FOREST DISTURBANCES

by
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STAR

Pacific Southwest Forest and Range Experiment Station
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ABSTRACT

The success of remote sensing for forest inventories depends on the development of dependable predictors of forest area, timber volume, and stand classifications. In October 1969, an investigation was begun near Atlanta, Georgia, to explore the possibilities of developing predictors for forest land and stand condition classifications using space photography. From this study we have found that forest area can be predicted with reasonable accuracy on space photographs using ocular techniques. Infrared color film is the best single multiband sensor for this purpose. Using the Apollo 9 infrared color photographs taken in March 1969 photo interpreters were able to predict forest area for small units consistently within 5 to 10 percent of ground truth. Approximately 5,000 density data points were recorded for 14 scan lines selected at random from five study blocks. The mean densities and standard deviations were computed for 13 separate land-use classes. The results indicate that forest area cannot be separated from other land uses with a high degree of accuracy using optical film density alone. If, however, densities derived by introducing red, green, and blue cutoff filters in the optical system of the microdensitometer are combined with their differences and their ratios in regression analysis techniques, there is a good possibility of discriminating forest from all other classes.

ACKNOWLEDGEMENTS

This experiment is being performed under the Earth Resources Survey Program in Agriculture/Forestry under the sponsorship and financial assistance of the National Aeronautics and Space Administration, Contract No. R-09-038-002. This is the first progress report of a cooperative study with the Forest Service, U. S. Department of Agriculture. Salaries of all professional employees are being contributed by the Forest Service.

We want to thank the Aircraft Project Office of the Earth Orbital Missions Office, Manned Spacecraft Center, Houston, Texas, for high altitude RB-57 data used in this research.

Forest Service aerial photography and all color and black-and-white reproductions used in this experiment were the products of Richard J. Myhre, Photographer. John Noble ably assisted in photo interpretation and other phases of the work. Computer programming was done by Marilyn Wilkes.

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THE USE OF SPACE AND HIGH-ALTITUDE AERIAL PHOTOGRAPHY TO CLASSIFY FOREST LAND AND TO DETECT FOREST DISTURBANCES

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Introduction

The application of remote sensing on extensive forest inventories depends on the development of dependable predictors of forest area and timber volume and condition classifications. The first question that must be answered is: "How can forest be separated from nonforest land?" Once this problem has been overcome, the next goal is timber volume. What associated factors such as stand composition, stand density, physiographic or other site classification can be recognized? If we can reduce variation in mean volume per unit of forest area using recognizable strata on space or high-altitude photography, then more effective and efficient sampling designs can be used. These in turn should reduce data acquisition costs and improve forest information.

There are even greater challenges for remote sensing of the forest environment--the changes created by man-made and natural disturbances. For instance, forest land clearing, timber harvesting, or destructive agents such as fire, insects and disease cause large losses in standing volume and growth potential. The detection and measurement of these disturbances should enhance the future of remote sensing in forest inventories.

In October 1969, the Forest Service remote sensing research project at Berkeley began a program of research to seek solutions to these forest inventory problems. Our objectives during the first year were (1) to define the limits of accuracy and minimum areas for classifying land use on space photography, and (2) to determine the feasibility of using space photography to detect and outline disturbances in the forest communities. Some of the more significant results of this study are reported here.

The Study Area

The study area is located southwest of Atlanta, Georgia, and is one of two areas used in the forest inventory study reported by Langley[1] a year ago (Figure 1). We selected this area for several reasons, not the least of which is the excellent photographic coverage provided by Apollo 9 in March 1969. Another important reason is the geographic location. This area lies in one of the best timber growing regions of the country with diversified forest types and many different growing conditions. Furthermore, a wide variety of industries, including manufacturing, agricultural cash crops, livestock, and forest industry support the local economy. As a result, many land-use patterns and land-management practices present a challenge to remote sensing. The nearness of Atlanta, the transportation hub of the South, makes this area extremely accessible and subjects the area to changes created by a growing urban environment.

Our final reason for selecting this area was the result of our 1969 multistage forest inventory study. By studying this area in greater depth, we hope to improve predictions for volume stratification on space photographs which will lead to greater sampling efficiency.

This area is located in the southern piedmont land resources subregion.[2] It is about 60 percent forested, mainly in farm woodlands. The elevations range from about 250 meters (800 feet) in the southeast to 400 meters (1300 feet) in the northwest. The topography is gently rolling to hilly and

Figure 1. Apollo 9 coverage for a portion of the Atlanta test site (Site 217). The light gray area in the upper right corner is Atlanta, Georgia. This photo was made from an IR color transparency.

is cut by many narrow stream bottoms. Mean annual rainfall is approximately 25 centimeters (50 inches). The soils are primarily red and yellow podzolics. Major forest types in this region are loblolly-shortleaf pine and oak-pine[2]. In addition to loblolly (Pinus taeda), shortleaf (Pinus echinata), and other southern pines, several oaks (Quercus sp.), hickories (Carya sp.), yellow poplar (Liriodendron tulipifera), black gum (Nyssa sylvatica), and sweet gum (Liquidambar styraciflua) are plentiful in a variety of mixtures.

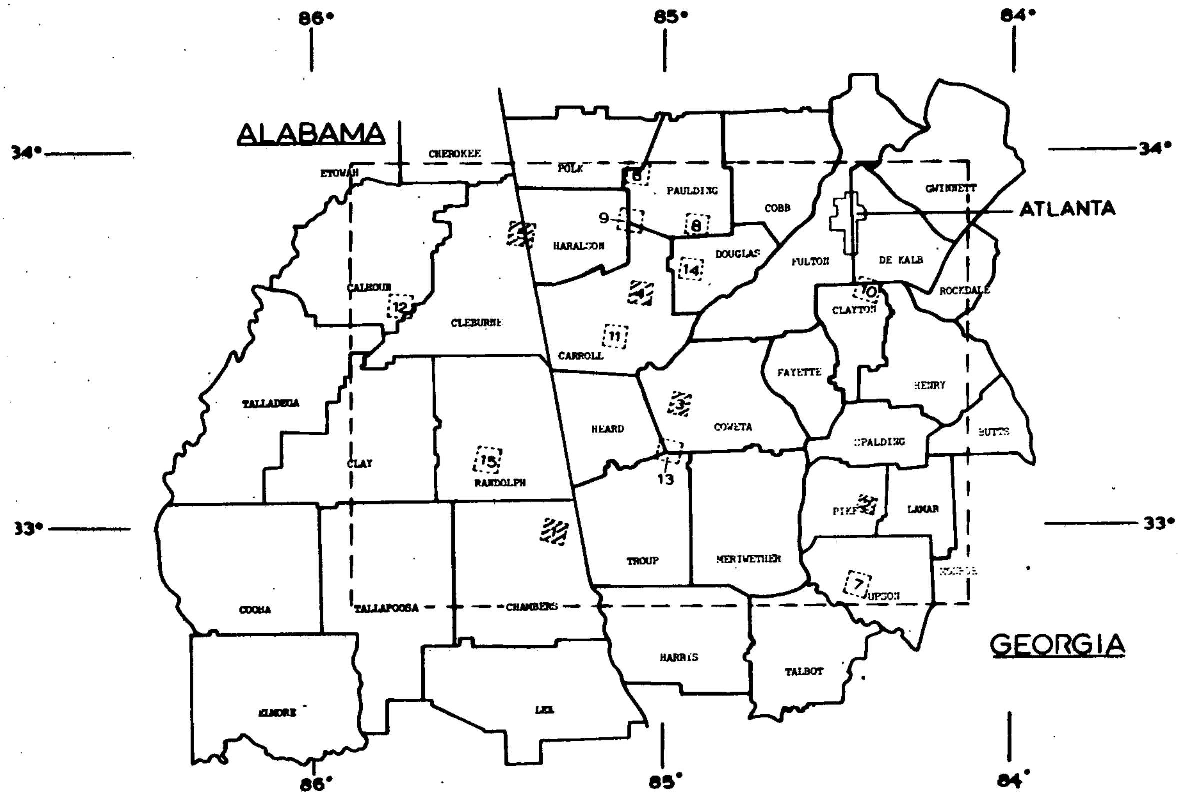
Remote Sensor Data Acquisition

Since March 1969 we have accumulated an assortment of remote sensor data to support this study. These data range all the way from 1:2,000 color transparencies to the Apollo 9 space photographs. A review of these data seems essential at this time.

Forest Service Photography

In April 1969, the Forest Service remote sensing aircraft flew multi-scale photography for five 6.4 kilometer (4 mile) square blocks used in the 1969 inventory study (Figure 2). This consisted primarily of 70 mm. photography for randomly selected sample strips. The photographic data are shown in Table 1. The high quality large-scale color photographs have been useful in establishing land-use and forest classifications at the time of the Apollo 9 flight. Small-scale Polaroid and Aero Neg color have been useful for planning and directing field crews to ground locations.

In March of this year, almost one year following the Apollo 9 flight, we rephotographed each of the five study blocks using Ektachrome infrared color film (8443) at a 1:32,000 scale; the photographs were taken with a Zeiss RMK21/23 camera. We also photographed one of the random sample strips with Eastman Aero Neg color film at a 1:12,000 scale. Ten additional 6.4



FOREST INVENTORY STUDY AREA

Figure 2. The Atlanta test site includes all or portions of 27 counties in Alabama and Georgia. Five intensive study areas are shown with hatch marks. The 10 additional squares will be used to test interpretation models in another phase of this study.

Camera	Focal Length (mm.)	Film	Filter	Scale	Coverage
Crown Graphic	75	Polaroid 400	Wratten 12	1:60,000	Block (5)
Maurer KB-8	38	Eastman Aero Neg	HF-3	1:120,000	Block (5)
Maurer KB-8	228	Ekta IR color	Wratten 15	1:20,000	Strip (5)
Maurer KB-8	38	Eastman Aero Neg	HF-2	1:12,000	Strip (10)
Maurer KB-8	228	Ansco D/200	1A	1:2,000	Strip (174 sample triplets)

Table 1. Camera, focal length, film/filter data, scale, and type of coverage for Apollo 9 forest inventory study support photography; April 1969.

kilometer (4 mile) square blocks were selected at random and photographed at this same time. These new blocks will be used in the next phase of the study to test interpretation training models as they are developed.

The 1:32,000 IR color photography and ground observations are being used to check photo classification made by both manual and automated interpretation techniques on small-scale simulated space photography provided by RB-57 high altitude flights.

NASA RB-57 Photography

In June 1970 we acquired our first coverage of the Atlanta test site by an RB-57 high altitude flight (Mission #131). The entire test site was covered in seven flight lines (Figure 3). For this mission we requested and received the data described in Table 2.

Copies of the Mission 131 data were received on July 30--eight weeks following the flight. In terms of coverage the flight was successful. Of the 15 6.4 kilometer (4 mile) square study blocks, all but one was completely covered by the smallest scale photography. Unfortunately, this block was one of five intensive study blocks to be used in developing training models. Four of the five blocks were covered by the 1:120,000 scale RC-8 Ektachrome photography. Only one block was entirely covered by the largest scale Zeiss photography, but this was to be expected due to the limited sidelap with this camera.

Of all the data received, only the RC-8 Ektachrome film taken with a 425 mμ filter and the panchromatic and B/W infrared Hasselblad films were acceptable for our purposes. Poor filter selection and poor film manufacture can be blamed for the failures of the Ektachrome film with a 450 mμ filter and the infrared color films taken with both the Zeiss and Hasselblad cameras.

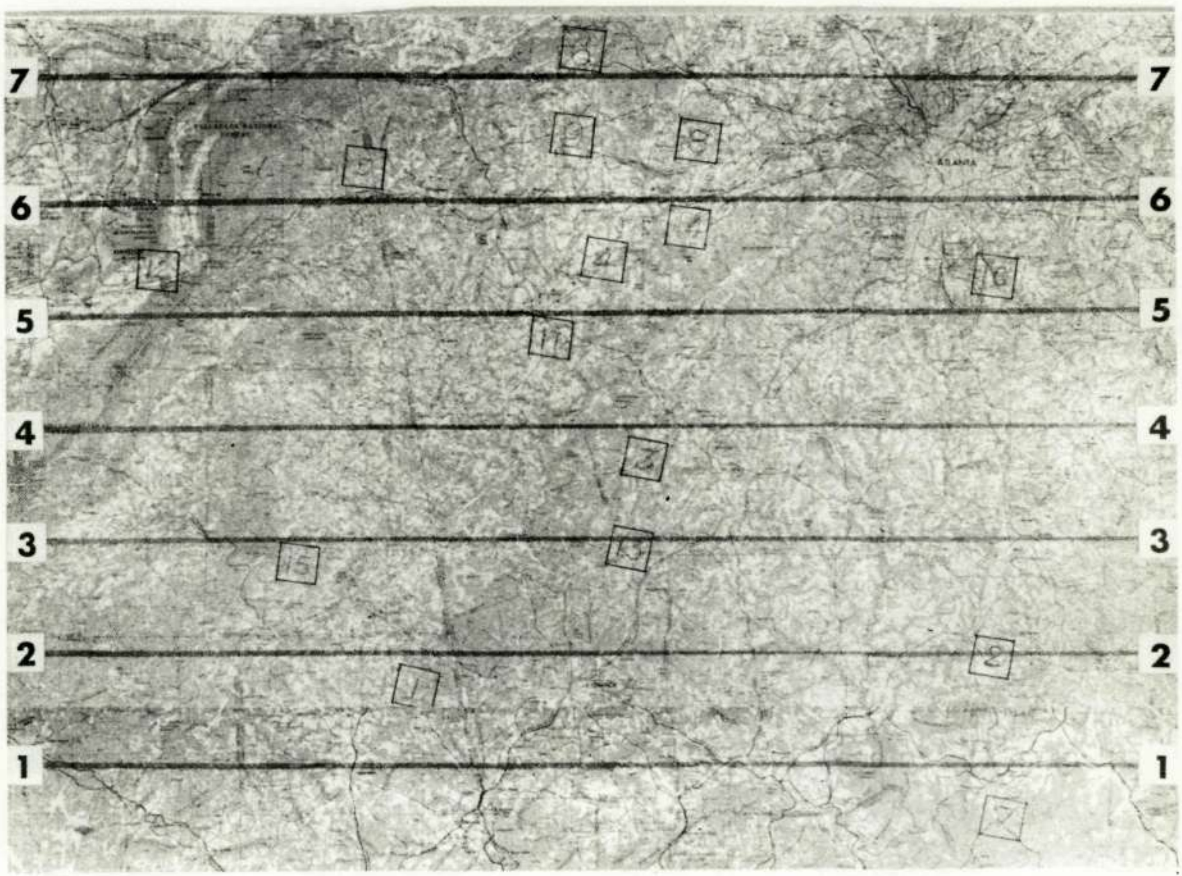


Figure 3. RB-57 Mission 131 covered the Atlanta test site in 7 flight lines.

Camera	Focal Length (mm.)	Film	Filter	Approximate Scale
RC-8	152	Ektachrome SO-397	450 mμ.	1:120,000
RC-8	152	Ektachrome SO-397	425 mμ.	1:120,000
Zeiss	305	Ektachrome IR SO-117	530 mμ.	1:60,000
Hasselblad	40	Panchromatic 2402	Wratten 25A	1:420,000
Hasselblad	40	Panchromatic 2402	Wratten 58B	1:420,000
Hasselblad	40	Panchromatic 2402	Wratten 12	1:420,000
Hasselblad	40	B/W IR, 2424	Wratten 89B	1:420,000
Hasselblad	40	B/W IR, 2424	Wratten 12	1:420,000
Hasselblad	40	Ektachrome IR SO-117	Wratten 15	1:420,000

Table 2. Camera, focal length, film/filter, and photographic scale for RB-57 (Mission 131) photography for site 217, Atlanta, Georgia; June 1970.

Photo Analysis Techniques

Both satellite and small-scale aerial photography require special techniques for data analysis. In this section we will discuss some of the techniques we used to overcome the problems of interpreting coarse resolution imagery.

Forest Area Predictions

The Apollo 9 space photographs were taken in March and provided some helpful characteristics to separate forest land from nonforest land[3]. First, the deciduous tree species (hardwoods) were without leaves. This leafless condition resulted in a distinctive bluish green color on the infrared color film that allows interpreters to evaluate where deciduous trees predominate. The contrast between bluish green deciduous forest and medium to dark purplish red evergreen (pine) forest separates these two pure types and helps to identify where mixtures of both pines and hardwoods occur. Another advantage to March photography is the absence of crops on the greater part of the active agriculture land. Although fields had been plowed in preparation for planting, it was evident that few crops other than overwintering grains and pasture were present. This cleared cropland condition made it possible to separate forest from a large portion of the nonforest land.

One important limitation of space photographs is the poor ground resolution. On the Apollo 9 IR color we found that the resolution was approximately 91 meters (300 feet). Thus, small fields in dark forested areas and small farm woodlots in lighter toned agricultural areas were not resolved. Although the human eye cannot resolve these small features, there is hope that microdensitometers may detect minute differences in color density and recognize spectral signatures for land use classification.[4,5]

Another limitation of satellite photography taken in March is the high ground water level resulting from winter and spring rains. High soil moisture and extremely high humus content of bottomland soils cause darker than normal images that may be mistaken for forest.

Using these criteria for interpretation, photo interpreters estimated the forest area within the five random 6.4 kilometer (4 mile) square study blocks on the Apollo 9 IR color film. Because of the small image size (6.4 kilometers equals 2.7 mm. on the photo), a Bausch & Lomb Zoom 70 stereoscope was used with 7.5X magnification (Figure 4). Although there is little or no stereoscopic effect, we viewed images on adjacent photographs simultaneously. The two images viewed together complemented one another and aided the interpretation.

To check forest area predictions made on the space photograph, photo interpreters estimated the area of forest and other land-use classes on conventional medium scale photography. Two sets of photographs were interpreted--the latest 1:20,000 Department of Agriculture (ASCS) panchromatic photography and 1:32,000 IR color photographs. The estimates were made using dot grid templates constructed to sample at an intensity of approximately 6.4 hectares (16 acres) per dot. This is more than ten times the intensity used by the U. S. Forest Service to estimate forest area on their nationwide forest survey. An Old Delft scanning stereoscope was used to aid in this interpretation.

Forest Mapping

We selected one block (Block 3) to check the Apollo 9 forest proportion and to explore the possibility of mapping broad forest types and nonforest classes on low-resolution photography. We examined Block 3 on the Apollo 9 IR color transparency using 7.5X magnification. Then using a 28X

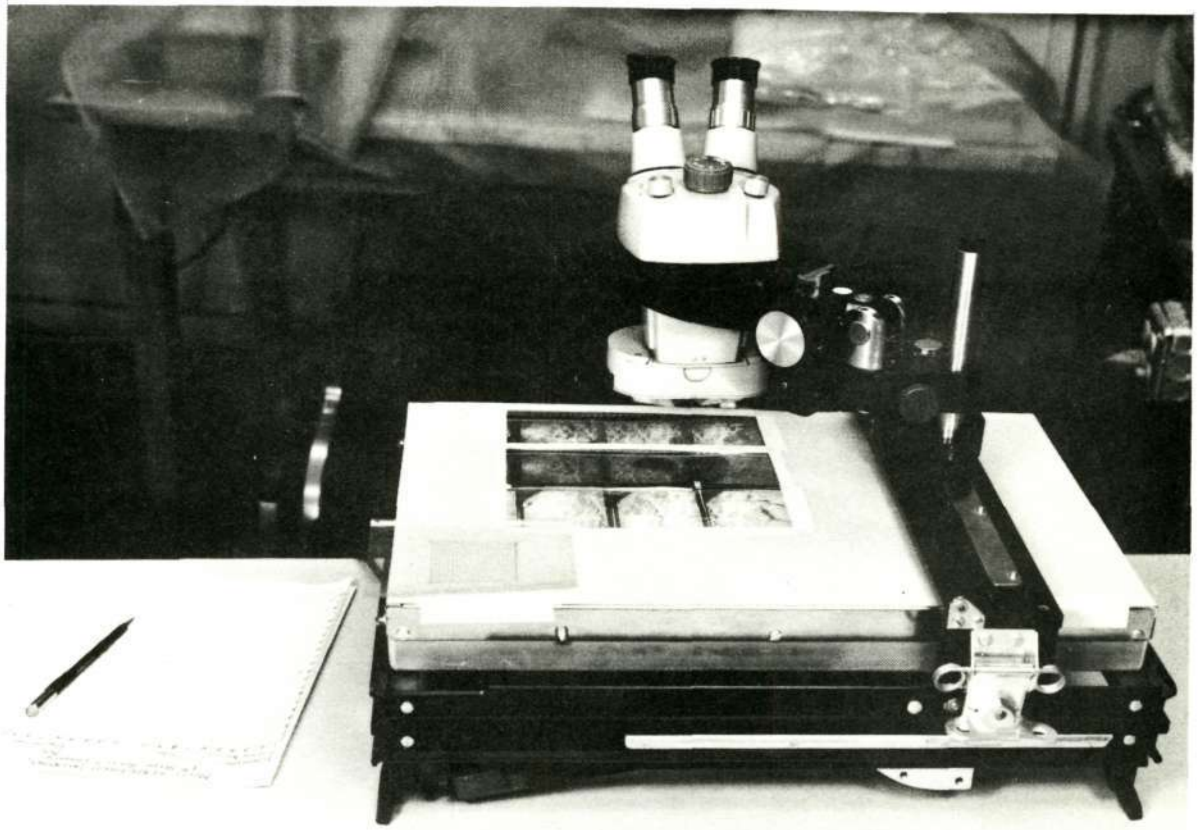


Figure 4. Interpreters used a Bausch & Lomb Zoom 70 stereoscope at 7.5X to interpret satellite photography.

panchromatic print enlargement made from the same photograph as a base map, we constructed a forest type land use map (Figure 5). A dot grid was constructed to sample approximately 6.4 hectares (16 acres) per dot. Using this grid, the percent forest was estimated in three broad types: pine, upland hardwood and bottomland hardwood. The percentage of the area in nonforest and water was also calculated. These data have been compared with estimates made on medium scale conventional photography.

Film Density Classification

A Photometric Data Systems microdensitometer was used to measure and record optical density along randomly selected sample strips on the Apollo 9 IR color transparency (Figure 6). The strips were first located on the 1:32,000 IR color transparencies taken in March 1970 (Figure 7). These strips are between 6.4 kilometers (4 miles) and 8 kilometers (5 miles) long and will be used to develop signatures to be used in interpretation training models. Well defined beginning and ending points were selected for each strip so that they could be transferred to both the Apollo 9 transparency and 1:420,000 scale photography supplied by NASA's high altitude aircraft.

Two interpreters classified and delineated nine nonforest and four forest classes along each of the fourteen lines (Table 3). These delineations were marked on a transparent overlay as shown in Figure 7. An Old Delft scanning stereoscope with 4X magnification was used to assist in the classification. We also estimated crown closure for forest in three classes, and forest disturbances were classified into ten classes. To help detect disturbances we compared each strip with the 1:12,000 photography taken in April 1969. When completed, the total length of line and length of each land use segment along the line was measured and recorded to the nearest 1/100 mm. There were over 800 segments delineated on over 96 kilometers (60 miles) of

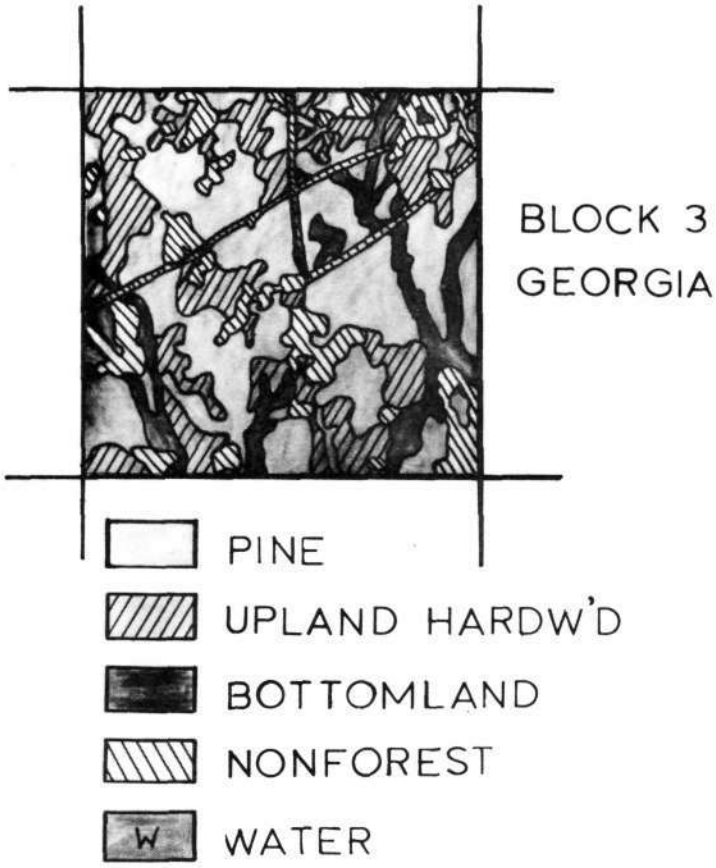


Figure 5. A forest type land use map was constructed using a 28X enlargement of Block 3 made from the Apollo 9 IR color as a base map.

Figure 6. A Photometric Data Systems microdensitometer coupled to a Data Acquisition System digitizer was used to scan the Apollo 9 and high altitude RB-57 photography.

Figure 7. Interpreters delineated forest type and land use along sample strips. These strips, adjusted by ground observations, are used as ground truth for microdensitometer scans on satellite and small-scale aerial photographs. Note beginning and ending points for the microdensitometer scans. The numbered observation points on strips 4 and 8 are illustrated in Figures 8 and 9, respectively.

Land Use	Code	Forest Condition	Code
Forest		**Forest Density**	
Pine (51-100% pine)	01	75-100 percent	1
Pine-Hardwood (25-50% pine)	02	25-75 percent	2
Bottomland Hardwood (0-25% pine)	03	0-25 percent	3
Upland Hardwood (0-25% pine)	04		
Agriculture		**Forest Disturbance**	
Crops	05	No disturbance	01
Plowed fields	06	Cutting - heavy	02
Pasture	07	Cutting - light	03
Idle	08	Land clearing	04
Abandoned	09	Insect damage - heavy	05
Orchard	10	Insect damage - light	06
		Disease damage - heavy	07
Urban	11	Disease damage - light	08
		Fire damage - heavy	09
Water		Fire damage - light	10
Turbid	12		
Clear	13		

Table 3. Land use and forest condition classification.

line.

We selected 107 segments from all forest and agricultural categories for ground observations. The number selected in each category was arbitrarily set to obtain a representative sample of each. Ground observations were made between June 8 and June 18, 1970. Forest points were given a type designation based on an estimate of basal area per acre by tree species. Crown closure (density) was assigned to each point by ocular estimate, and stand size was based on an estimated number of sawtimber, pole, and seedling and sapling size trees. In addition, each part of the forest floor was examined and classified into seven classes. Munsell color standards* were used for soil color classification. If we found a point that had been disturbed since March 1969, this was identified and recorded by cause.

Agricultural points were examined and classified by crop type and maturity, soil color, and erosion. Pasture land, idle land, and abandoned agriculture were classified by broad vegetation types, degree of grazing, erosion, and soil color. Both a 35 mm. color and infrared color photograph were taken on each forest and agricultural point to illustrate the conditions that we described. Some of the land classes in Block 4 are illustrated in Figures 8 and 9.

Using ground truth, we adjusted the photo interpretation along the sample strips to give a true picture of ground conditions. These adjusted photo data are known as our ground truth and are used to develop optical density signatures with an automatic scanning microdensitometer.

Using the microdensitometer, we scanned the 14 strips on Apollo 9 IR color frames 3791 and 3792. Because of the extremely small scale of this

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*Munsell Color Company. Munsell Book of Color. Ed. 1920-60. Baltimore, Md.

34

42

54

57

Figure 8. Each ground observation point was photographed between June 8 and June 18 to illustrate the forest and nonforest classifications. The numbered points along strip 4 in Figure 7 are illustrated above: (34) pole size (5-9 inch d.b.h.) loblolly pine with 75-100 percent crown closure, forest floor is leaf and needle litter with some ground cover plants; (42) moderately grazed pasture; (54) harvested hay field; (57) immature soybean crop.

12

16

26

38

42

Figure 9. Each ground observation point was photographed between June 8 and June 18 to illustrate the forest and nonforest classifications. The numbered points along strip 8 in Figure 7 are illustrated above: (12) abandoned agricultural field with high weeds; (16) abandoned agricultural field with high grass and weeds; (26) abandoned agricultural field with wild blackberry, weeds, and tree seedlings; (38) seedling and sapling size upland hardwoods with 25-75 percent crown closure, heavy underbrush, reproduction and ground cover plants; (42) moderately grazed pasture.

photography, we found that it was difficult to position the sample strips precisely for scanning. For this reason we developed a different technique. First we read the X and Y coordinates for the starting and ending points that we had selected and recorded them on tape. Then we programmed the microdensitometer to block-scan an area that included these two points. We used an effective aperture area of 18.67 μm and the microdensitometer was programmed to read at 9 μm intervals on scan lines 9 μm apart. The density readings along our sample line were determined by computer programming. The red, green, and blue mean densities and their standard deviations were computed for each land-use class by strips, blocks, and the sum of all blocks. These densities have been plotted for comparison.

We have not attempted to detect forest disturbances using the microdensitometer and automatic data processing. However, we did run a test on two areas with known disturbances. One is a stand of pine pulpwood that was cut some time between April 1969 and March 1970. The other is a natural gas pipeline that was constructed during the same period. First, we selected beginning and ending points for scan lines that would pass through these two areas. These points had to be recognizable on a small-scale Apollo 9 IR color and June RB-57 Hasselblad imagery. Then these two films were scanned and density read using red, blue, and green cutoff filters.

Results

When forest area predicted on Apollo 9 photographs was compared with forest area estimated on medium-scale aerial photographs, we found some interesting relationships. Despite the differences in scales, estimates of forest area made on the Apollo 9 photograph are correlated to some degree with estimates on 1:32,000 IR color made a year later (Table 4). Only in

Photography	Percent Forest Area (Block) 1	2	3	4	5	Mean
	%	%	%	%	%	%
Panchromatic[1] (1:20,000)	77	36	81	45	85	65
Polaroid[2] (1:60,000)	69	25	87	51	93	65
IR Color[1] (1:32,000)	83	39	86	68	86	72
Apollo 9[2] (1:2,430,000)	80	35	73	55	96	68

[1]Estimated from a count of over 600 photo points systematically located within each block.

[2]Ocular estimate.

Table 4. Comparison of percent forest area by study block mean for all blocks, and type of photography.

Blocks 3 and 4 does the difference exceed 10 percent. On Block 4, the difference can be explained in part by the lack of full coverage on the 1:32,000 photography. Unfortunately the western quarter of the block was not covered.

The forest area in Block 3 was underestimated on the Apollo 9 photo. This was verified by comparing the prediction with the mean of the other three estimates--the mean is 85 percent or 12 percent above the Apollo 9 prediction. To check this, a dot count was made on a forest type land use map constructed from the Apollo 9 photograph. This new prediction resulted in a forest area estimate of 80 percent and compares more favorably with the mean for the other three methods.

When we compare Block 3 area percentages by broad forest types there is some correlation between the Apollo 9 and the other two estimates (Table 5). All three scales resulted in bottomland hardwood estimates within one percent. Water area estimates are extremely close. The estimate of pine type acreage on the 1:32,000 IR color and Apollo 9 IR color were closer than we expected; the space photograph underestimated pine type by 15 percent. The extimate of pine type acreage on the 1:20,000 panchromatic photography has obviously been affected by poor type discrimination on this film. Also, of the three estimates this was made by the least experienced interpreter. Better instruments for viewing and drawing maps directly from this extremely small-scale photography should improve these results.

Figure 10 shows a comparison of optical density for the 13 forest and nonforest classes on Apollo 9 IR color photography. There were 4,985 data points involved in this analysis; 3,425 forest and 1,560 nonforest. Since we have used separate scans for red, green, and blue optical density this means that three times this number of data points were analyzed in the experiment.

Photography	Pine	Hardwood Upland	Hardwood Bottomland	Nonforest	Water
	%	%	%	%	%
Panchromatic (1:20,000)	17.0	54.1	9.8	18.9	0.2
IR Color (1:32,000)	59.4	16.7	10.1	13.2	0.6
Apollo 9 (1:2,430,000)	44.8	24.2	10.7	19.7	0.6

Table 5. Comparison of area for forest and nonforest classes using three photo scales--Block 3 (estimated from a count of over 600 photo points).

Using density alone, our data indicate that at a confidence limit of one standard deviation (68 percent) we can discriminate between forest land and agricultural crops, plowed fields, pasture land, idle land, orchards and turbid water. None of the three bands (red, green, or blue) appears to be better than another. Although at first glance the red band appears to have greater differences, the standard deviations for red density are greater than either green or blue. This would compensate for the greater density range shown in the curves.

Forest types cannot be separated based on density alone. The standard deviations about the means for density in all three bands overlap and reduce the probability of correct interpretation. However, the data do suggest that it may be possible to develop signatures for forest types, abandoned agriculture, urban and clear bodies of water using a combination of nine variables. These would include density, differences in density, and density ratios. For instance, the relationship of red density to blue and green density appears to provide a signature for recognizing forest from crops, plowed fields, idle, abandoned, orchard, urban areas and turbid water.

Phenological development of vegetation and sun altitude will affect spectral reflectance and the response of film emulsions. Thus, it is important to study these effects so that imagery from the Earth Resources Technology Satellites (ERTS), in 1972, can be selected to provide the type of information desired. The Earth Resources Program at NASA's Manned Spacecraft Center in Houston, Texas, is providing high-altitude multiband imagery for studies of this nature.

We have just begun to process multiband imagery taken from 18,288 meters (60,000 feet) by high-altitude aircraft from NASA's Manned Spacecraft Center in Houston. This is the first in a series of photographic flights

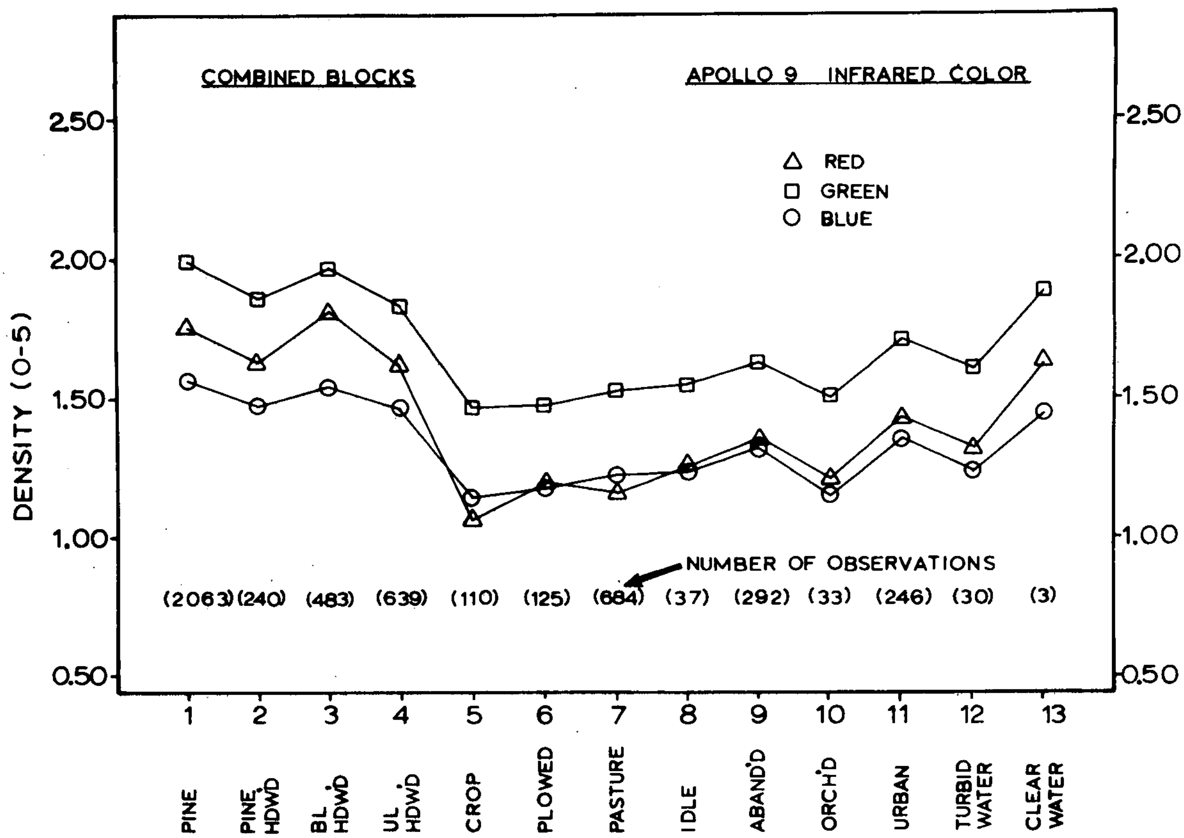


Figure 10. The mean red, green, and blue optical densities for 13 forest and nonforest classes on Apollo 9 IR color, combined for all blocks.

that will include early summer, late summer, fall and winter conditions. The first films to be processed were taken in June 1970. Only one (Block 5) has been completed. Since this block is 90 percent forested it is not a good example for land-use discrimination. However, it does show discrimination possibilities between forest types.

We processed the IR color film with a red, green, blue, and clear filter using the same scanning procedure as described for the Apollo 9 films. The only difference is that we used a 99.17 μm. effective aperture size to scan approximately the same strip width in terms of ground resolution. Our data were collected at 51 μm. apart.

Figure 11 shows a comparison of red, green, and blue optical density measured on 1:420,000 infrared color film. Comparing these results with densities from Block 5 on the Apollo 9 infrared color film shows some interesting differences. The three month difference in vegetation development between photography dates accounts for the big increase in red density levels (infrared response). Obviously, June photography with greater leaf cover should have a higher red density than March photography when deciduous trees are leafless, most vegetation is still dormant, and solar radiation is still rather low by comparison. It is interesting to note the similarity in shapes of the two sets of curves. Although these data are encouraging, we can attach very little significance to them because the RB-57 IR color film was of such poor quality. However, our conclusions based on these data are the same as those for the Apollo 9 density scans. That is, density alone may discriminate forest from several nonforest classes, but to discriminate forest, forest types, and all nonforest classes will require combinations of density and between density relationships.

The microdensitometer scans made on three different B/W infrared and

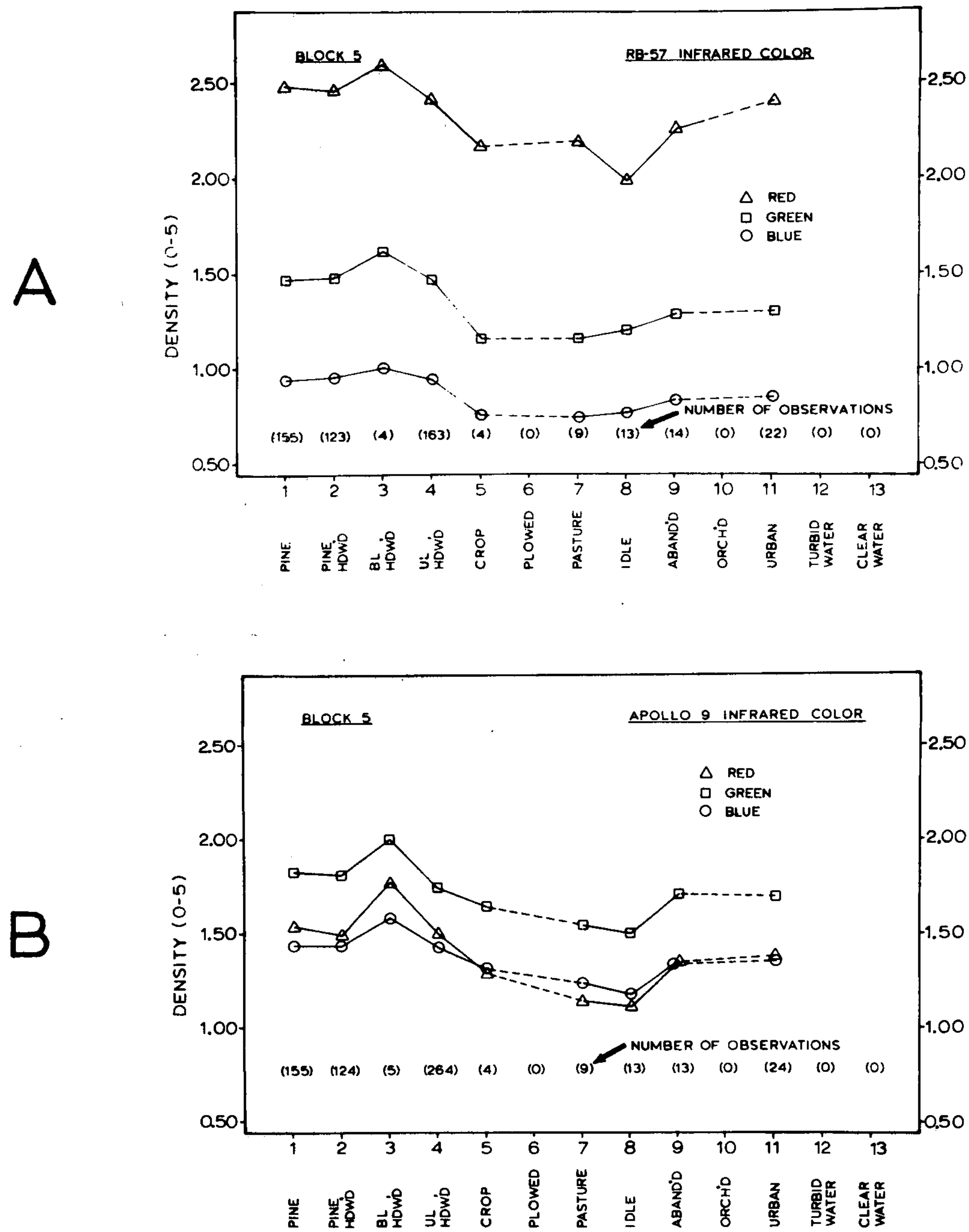


Figure 11. The mean red, green, and blue optical densities for 9 of 13 forest and nonforest classes: (A) 1:420,000 IR color high-altitude photography; (B) Apollo 9 IR color--Block 5 only.

panchromatic film/filter combinations resulted in the mean densities plotted in Figure 12. We do not show the densities for infrared film with a Wratten 12 filter and panchromatic film with a Wratten 12 filter because they appear to provide very little information for this study. It is obvious from the three curves that the infrared film with a Wratten 89B filter shows limited value for forest/nonforest discrimination by itself. Future analyses may show, however, that this film, when coupled with infrared color film, will aid in differentiating between bodies of water and forest. Although we have no data at present to support this point, an examination of the photographs shows that bodies of water are enhanced on this film. This has been a weakness of the IR color film taken from space. Bodies of water in dark forested backgrounds are not resolved.

Of the two panchromatic film/filter combinations shown, only the panchromatic with a 25A filter indicates any potential for land-use classification. Here again, the discimination of urban areas may be aided if this film is used on concert with the IR color film. The better resolution capabilities of this film/filter combination may aid in resolving narrow urban features such as highways, pipelines, and power lines that are not resolved on the infrared color taken from space altitudes.

Detecting and measuring changes in the forest environment created by urban development and other man-made and natural causes is important to keep forest information up to date. The microdensitometer scans in Figure 13a are meant to demonstrate the feasibility of automatic scanning microdensitometers to detect a pulpwood cutting by repetitive satellite imagery. We used red density on the Apollo 9 IR color and blue density on the RB-57 IR color because they appeared to show the best discrimination.

The photographs in Figure 13b show the pulpwood stand before and after

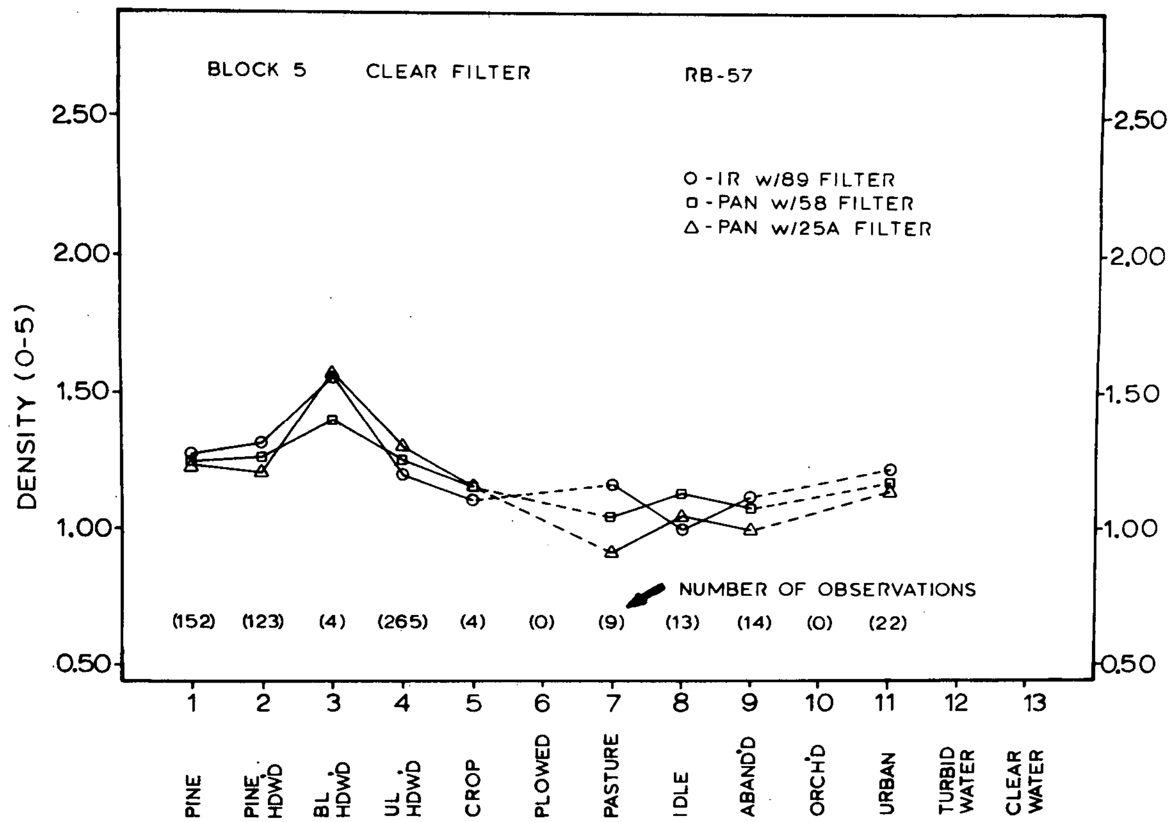


Figure 12. The mean optical density (no filter) for 9 of 13 forest and non-forest classes on panchromatic (Wratten 25A), panchromatic (Wratten 58B), and B/W infrared (Wratten 89B)--Block 5 only.

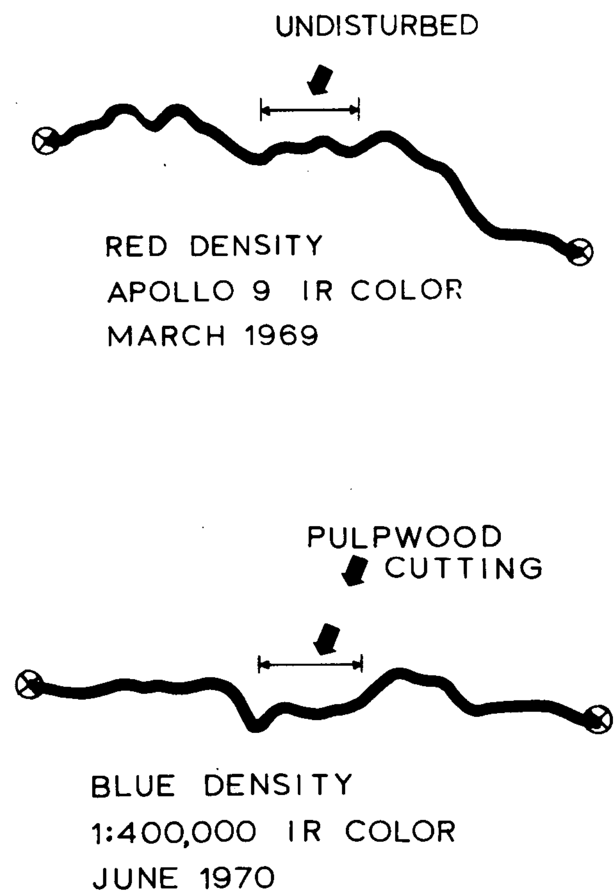
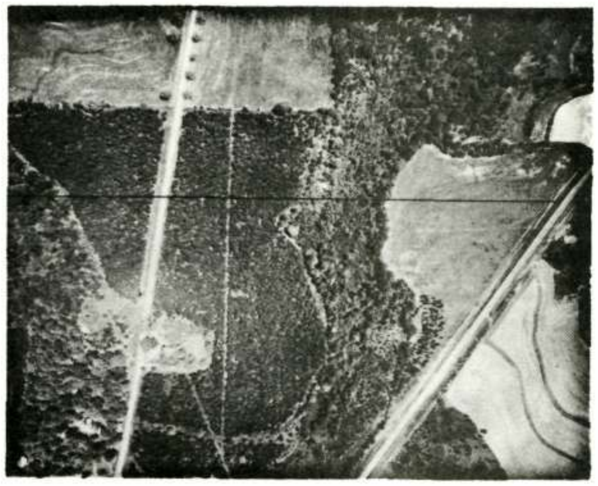


Figure 13a. A pulpwood cutting that occurred some time after the Apollo 9 mission, but before RB-57 Mission 131, is shown detected by a microdensitometer scan. The upper density trace was made using a red filter on the Apollo 9 IR color photograph. The lower density trace was made using a blue filter on the 1:420,000 scale IR color taken on the RB-57 Mission 131.

BEFORE CUTTING APRIL 1969



AFTER CUTTING MARCH 1970

Figure 13b. The pulpwood cutting shown on the density trace in Figure 13a does not appear in the top photo taken in April 1969. A photograph (IR color) taken in March 1970, one year following Apollo 9, shows that the pulpwood stand has been cut.

the cutting. Some of the differences in the shapes of the two curves can be attributed to film resolution as well as seasonal responses for vegetation on IR color film. Despite these differences, there is certainly a noticeable response at the site of the pulpwood cutting.

Figures 14a and 14b show a similar demonstration for a pipeline location. Although we have much to learn about how to interpret these data by data processing, it does show some hope for detecting areas of forest change even on satellite imagery.

Conclusions

Although the research reported here is in its preliminary stages, we can make four rather broad statements regarding the results of this work:

(1) Infrared color film is the best single multiband sensor available at the present time.

(2) There is a very good possibility that we can separate forest from all nonforest land uses by micro-image evaluation techniques on IR color film coupled with B/W infrared (Wratten 89B filter) and panchromatic film (Wratten 25A filter).

(3) Discrimination of forest and nonforest classes may be possible by either of two methods:

(a) Interpreters with appropriate viewing and mapping instruments might simultaneously view enlarged multiscaled images and map forest types and land uses for estimating acreages, or

(b) Programmable automatic scanning microdensitometers and automatic data processing techniques may be used to make land-use decisions based on optical densities, density differences, and density ratios.

(4) Results show the importance of procuring the best possible remote

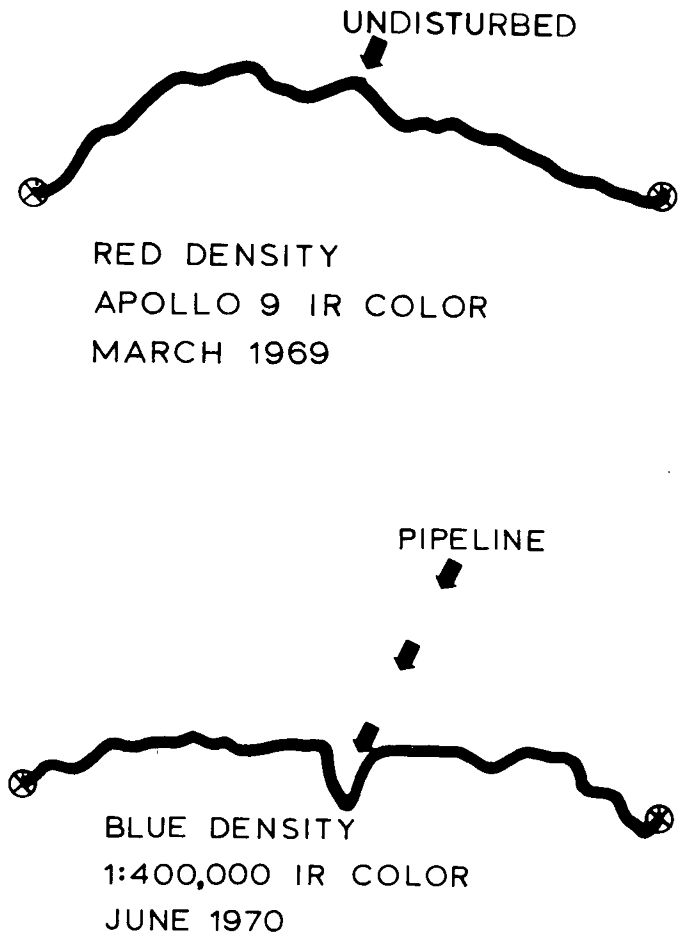
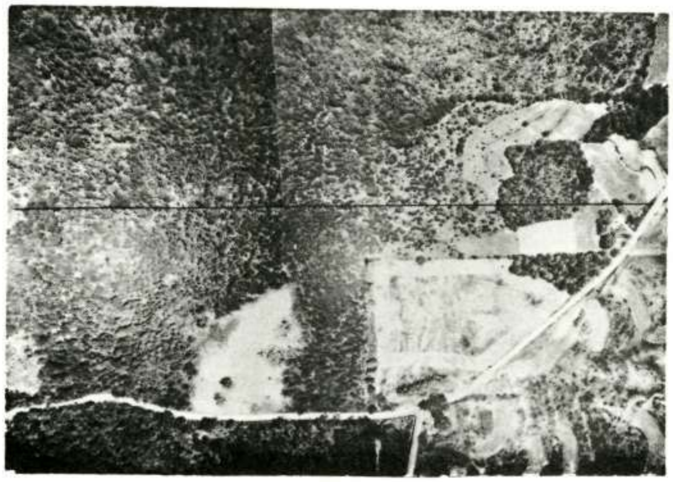


Figure 14a. A pipeline constructed some time after the Apollo 9 mission but before RB-57 Mission 131 is shown detected by a microdensitometer scan. The upper density trace was made using a red filter on the Apollo 9 IR color photograph. The lower density trace was made using a blue filter on the 1:420,000 scale IR color photograph taken on RB-57 Mission 131.

BEFORE PIPELINE APRIL 1969



AFTER PIPELINE MARCH 1970

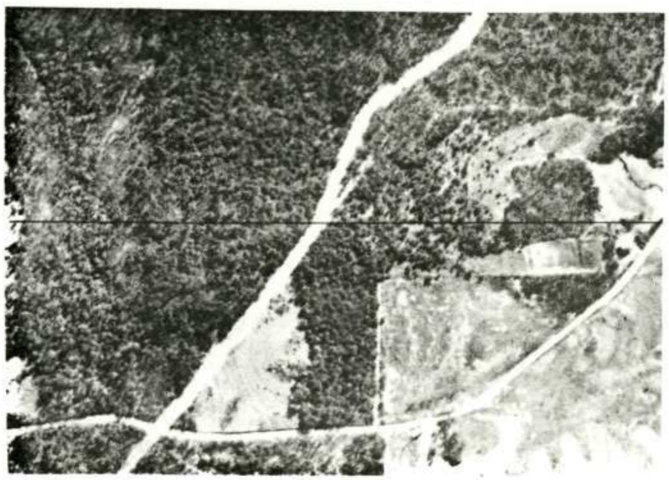


Figure 14b. The pipeline shown on the density trace in Figure 14a does not appear on the top photo taken in April 1969. A photograph (IR color) taken in March 1970, one year following Apollo 9, shows the pipeline very clearly.

sensor data possible. Without good data our efforts can be of little significance.

Our plans for next year include continued efforts to develop optical density signatures for forest and nonforest classes on Apollo 9 photography. Signatures developed for IR color, panchromatic (Wratten 25A filter), and B/W infrared (Wratten 89B filter) will be compared with signatures developed for RB-57 high-altitude photography for three seasons and 1:32:000 IR color taken in March 1970. We will also study the use of several pattern recognition techniques using density signatures.

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